A NEW TEMPERATURE COMPENSATED CURRENT CONTROLLED CONVEYOR

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Abstract: A simple and effective temperature compensation scheme which generates approximately temperature-independent output current for a current controlled conveyor and its application to a current-mode oscillator is designed and introduced. The temperature sensitivity of the current controlled conveyor's parasitic resistance is reduced by this new design. This proposed circuit includes two current conveyors and a translinear circuit. The circuits' theoretical analysis was carried out, and the performance of the block circuit was confirmed through PSpice simulation results. From the simulation results for applications of proposed circuit, we found that the circuit's temperature-dependence was reduced.

Novo temperaturno kompenzirano vezje CCCII

Kjučne besede: CCCII, temperaturna kompenzacija, vezje, SPice simulacija

Izvleček: V članku opišemo enostaven in učinkovit pristop k izvedbi tokovno krmiljenega in temperaturno kompenziranega vezja CCCII, kakor tudi njegovo uporabo pri izvedbi tokovno krmiljenega oscilatorja. Z novim pristopom znižamo temperaturno občutljivost parazitnih uporov CCCII. Opravili smo teoretično analizo vezja in potrdili funkcionalnost posameznih blokov s pomočjo PSpive simulacije. Iz rezultatov sklepamo, da smo vezju za to uporabo močno zmanjšali temperaturno odvisnost.

1. Introduction

Until recently, a current-mode circuit has been used as the main building block in circuit design. The fact that the gain-bandwidth product is fixed in voltage mode circuits and the slew rate is bounded are disadvantages in many electronic circuit applications. Because current-mode circuits have a number of positive characteristics, such as large bandwidth, high slew rate, wide dynamic range, low power consumption, basic circuit structure and wide linearity, they are used widely in electronic circuit design, especially for oscillator and filter circuits /1-4/.

Current conveyors and related current-mode circuits have begun to emerge as an important class of circuits with properties that enable them to surpass their voltage-mode counterparts in a wide range of applications. A current-mode approach is not just restricted to current processing, but it offers important advantages when interfaced to voltage-mode circuits. The Current Controlled Conveyor (CCCII) which is electronically controllable by a biasing current has been employed in many applications /5,6/. CCCII has been used as a part of filters, oscillators, multipliers and many current-mode applications that require temperature compensation /6-8/. Parasitic resistance is essentially a disadvantage in electronic circuits. But it is used to advantage in current controlled conveyor circuits because it can be easily controlled by biasing current. Output current is negatively affected by the temperature dependence of this resistance /9/. This resistance is directly proportional to thermal voltage for bipolar technology /10/ and surface mobility ($\mu$) for CMOS technology /11/. This means that the characteristics of the current controlled current conveyor-based circuits will depend strongly on the absolute temperature. Also the MOS transconductance parameter is affected by a strong dependence on temperature /12/. Therefore, a technique for temperature compensation is required. In a previous study /16/, a temperature compensated scheme for a translinear current conveyor-based circuit was investigated. This scheme had a disadvantage because it includes a resistor as a passive component. Also the temperature coefficient of the resistor was neglected in that work /16/. Until now, it is not shown that temperature compensated CCCII is used some where else.

In this study, a new circuit building block which consists of two CCCIIIs and a translinear circuit block was designed for temperature compensation. The new building block, called the temperature compensated current controlled conveyor (TC-CCCII) has no passive component. Parasitic resistance's temperature dependence is eliminated, so that temperature compensation can be provided for the output current of the current conveyor. To demonstrate the proposed circuit's easy applicability it was used in a CCCII-based oscillator. The circuits' theoretical analysis was carried out, and the simulation process was realized using a PSpice electronic circuit simulation program. Simulation results verify the theoretical considerations.
2. Current controlled conveyor

A conventional current controlled conveyor is given in Fig. 1. Port characteristics of the current controlled conveyor are given in (1)/14/.

\[
\begin{pmatrix}
I_x \\
V_y \\
I_z
\end{pmatrix} =
\begin{pmatrix}
0 & 0 & 0 \\
1 & R_x & 0 \\
0 & 1 & 0
\end{pmatrix}
\begin{pmatrix}
V_x \\
I_x \\
V_z
\end{pmatrix}
\]  

(1)

Fig. 1. Conventional CCCII; (a) Symbol, (b) Circuit diagram

When port Y of the CCCII is grounded and port X constitutes the input of the circuit (Fig. 1), the input current is then given by

\[
I_x = 2I_0 \sinh\left(\frac{V_x}{V_T}\right)
\]  

(2)

In CCCII based circuits, realization methods take advantage of the parasitic resistance \(R_x\) that appears at port X of the conveyor. Hence, the resistance \(R_x\), which can be varied by means of an external bias current. From (2), if \(V_x < < V_T\) is assumed, then the function \(\sinh\left(\frac{V_x}{V_T}\right)\) is approximately equal to \(\frac{V_x}{V_T}\). The expression for this equivalent resistance is

\[
R_x = \frac{V_x}{I_x} = \frac{V_x}{2I_0}
\]  

(3)

where \(V_x\) is the thermal voltage given by \(kT/q\) and \(I_0\) is an external bias current /9/. This means that the characteristic of the current conveyor based circuits will depend strongly on temperature. Therefore, some form of temperature compensation is required. The relation between ports X and Y can be modeled as shown in Fig. 2.

Fig. 2. Equivalent circuit between ports Y and X

3. Proposed circuit topology

Fig. 3 shows symbol and schematic diagram for the proposed temperature compensated current controlled conveyor (TC-CCCII).

Fig. 3. Proposed TC-CCCII; (a) Schematic diagram, (b) Symbol

The temperature compensated current controlled conveyor was designed using two current conveyors and a translinear (TL) circuit block based on translinear principle.

Currents \(I_{01}\) and \(I_{02}\) denote bias currents for the first and second current conveyors, respectively, and \(V_s\) is an external voltage. Fig. 4 shows the circuit structure of the TC-CCCII.

When port X of the first CCCII (X1) is grounded and port Y of the first current conveyor (Y1) constitutes the input of the proposed circuit, the output current of the first current conveyor (\(I_{Z1}\)), which is equal to current that exists at port X of the first current conveyor, can be expressed as

\[
I_{Z1} = 2I_{01} \frac{V_s}{V_T}
\]  

(4)

It is shown that output current \(I_{Z1}\) of the first current conveyor depends on the voltage \(V_s\) applied to port Y1 and the bias current of the first current conveyor \(I_{01}\) in (4).

A translinear circuit is used as a current divider circuit to generate bias current for CCCII. This circuit is almost temperature-independent. This circuit is presented in Fig. 5.

The relations among the currents in this circuit are given in (5).
where \( I_{o2} \) is the bias current of the second current conveyor aiming at providing temperature compensation. As shown in Fig. 4, \( I_1 \) and \( I_2 \) are the collector currents of the \( Q_{37} \) and \( Q_{C} \) transistors respectively. The current of the second current conveyor’s port \( X \) can be expressed as

\[
I_x = 2I_{o2} \frac{V_y}{V_x}
\]  

(6)

In this case, the current of the second current conveyor’s port \( X \) will be

\[
I_x = \frac{I_{o2} V_y}{I_{o1} V_x}
\]  

(7)

Current mirrors which are obtained by \( Q_{11}, Q_{12} \) and \( Q_{B}, Q_{C} \) transistors allow the biasing current \( I_{o1} \) to flow through the \( Q_{B} \) transistor at the collector of the \( Q_{C} \) and \( Q_{C} \) transistors. So \( I_1 \) and \( I_2 \) currents are equal to current \( I_{o1} \). From (7), we can see that the parasitic resistance of the second current conveyor can be expressed as,

\[
R_x = \frac{V_x}{I_{o1}}
\]  

(8)

The parasitic resistance \( R_x \) input current \( I_x \) and output current \( I_z \) of the whole circuit can be independent from \( V_T \) by adjusting the suitable configuration of the circuit blocks.

![Fig. 4. Realization of the TC-CCCII circuit](image)

### 4. Simulation results

To verify the validity of the theory, the circuits in Fig. 1 and Fig. 4 were simulated using models for the transistors of type NR100N and PR100N whose parameters are detailed in /15/. The biasing current \( I_{o1} = 85 \mu A \), that is, \( R_x = 150 \Omega \) was used for the conventional current conveyor. The circuit parameters were chosen as \( I_{o1} = 100 \mu A \) and \( V_x = 15 \text{ mV} \) for the temperature compensated current conveyor, and the power supply was \( \pm 2.5 \text{ V} \).

First, a simulation of the conventional current conveyor shown in Fig. 1 was realized using a PSpice simulation program. Port Y of the CCCII was grounded and port X constituted the input of the circuit. The I-V characteristic at port X for different temperature values are shown in Fig. 6.

From (1), \( I_z \) is equal to \( I_x \). Thus, from Fig. 6 it is concluded that \( I_z \) is affected by temperature change.

![Fig. 5. Translinear circuit](image)

Next, a simulation of the temperature compensated current conveyor was realized using a PSpice simulation program. Port Y of the second CCCII was grounded and port X of the second CCCII constituted the input of the circuit. The I-V characteristic at port X for different temperature values are shown in Fig. 7.

![Fig. 6. Current-voltage characteristics of the CCCII without temperature compensation](image)

![Fig. 7. Current-voltage characteristics of the TC-CCCII](image)

In Fig. 7, it is clear that the output current for different temperature values changes in regard to nanoamperes. These values are almost negligible. In addition, when Fig. 7 is taken into consideration, it does not show a characteristic deviation in the origin, on the contrary in Fig. 6. Characteristic deviation in the origin is caused by a mismatch.
between the transistors. This situation clearly denotes that the proposed circuit is more stable.

Fig. 8 depicts changing output current versus temperature for both the conventional and the temperature compensated CCCII’s output current.

In Table 1, it is clear that $R_x$ and oscillation frequency for different temperature values change. Biasing currents were chosen as $I_0 = 250 \mu A$ for conventional CCCII.

To demonstrate the applicability of the new temperature compensated CCCII, it was used in place of a conventional CCCII to realize temperature compensation in the current controlled oscillator.

Circuit parameters were chosen as $I_0 = 75 \mu A$ and $V_0 = 15$ mV for the temperature compensated current conveyor in Fig. 4 and the power supply was $\pm 2.5$ V. $C_1$ and $C_2$ were 0.01 μF for all simulations.

Simulation results are shown in Fig. 10, which displays current amplitude against frequency for a number of temperatures for the current controlled oscillator based on a conventional CCCII. This graph was obtained from an oscillator circuit using conventional CCCII.

5. Current controlled oscillator based on cccii

The oscillator was designed using a current amplifier (current mirror) and two TC-CCCIIs as shown in Fig. 9.

The current loop gain or the return ratio $T(s)$ of the circuit at port $X$ is characterised by

$$T(s) = \frac{aR_x C_5 S}{1 + 2R_x C_5 S + 2R_x C_5 C_6 S^2}$$  \hspace{1cm} (9)

CCCII has a finite input resistance $R_x$ at the X terminal, which is controllable by the bias current $I_0$. $R_x$ is considerably affected by temperature. Sinusoidal oscillation frequency is shown in the following equation

$$f_0 = \frac{1}{2aR_x \sqrt{C_5 C_6}}$$  \hspace{1cm} (10)

where the oscillation condition is $\alpha = 2$. Oscillation frequency can be tuned by varying the $R_x$. The current mirror in Fig. 9 is independent from temperature, so oscillation frequency is not affected under this condition. Table 1 depicts a theoretical changing $R_x$ and oscillation frequency versus temperature for the conventional CCCII.

Table 1. Theoretical changing $R_x$ and oscillation frequency versus temperature for the conventional CCCII.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>$R_x$ (Ω)</th>
<th>Frequency (KHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>46.94</td>
<td>335.06</td>
</tr>
<tr>
<td>30</td>
<td>52.12</td>
<td>305.38</td>
</tr>
<tr>
<td>60</td>
<td>57.28</td>
<td>277.87</td>
</tr>
<tr>
<td>90</td>
<td>62.44</td>
<td>254.91</td>
</tr>
</tbody>
</table>

Fig. 10. Unstable oscillation frequency at different temperatures for oscillator based on conventional CCCII.
In Fig. 10, it is clear that, the oscillator's oscillation frequency is strongly affected by temperature change. The oscillation frequency of the circuit changes between 265 KHz - 340 KHz.

Fig. 11 shows stable oscillator frequency at different temperature values for the current controlled oscillator based on the temperature compensated CCCII. This graph was obtained from an oscillator circuit using the TC-CCCII.

It is clear that the temperature performance of the compensation circuit is much better than that of the conventional circuit. In addition, it can also be seen that the compensated circuit results in a much lower temperature sensitivity.

6. Conclusion

In this study, a temperature compensated circuit for conventional CCCII was designed, and its application to a current-mode oscillator was tested. The temperature sensitivity of the current controlled conveyor's parasitic resistance was reduced in this new design. The proposed circuit was simulated using a PSpice simulation program, and its simulation results were compared with the simulation results of a conventional CCCII. The compensated circuit was less temperature sensitive than conventional circuits. However, the proposed circuit was found to be suitable for implementing in integrated circuits due to its having no passive element. To demonstrate the applicability of the new temperature compensated CCCII, it was used in place of a conventional CCCII to realize temperature compensation in a current controlled oscillator. Finally, the proposed circuit which is controllable by biasing current was used as a part of many sensitive current-mode applications that especially require temperature compensation.

7. References


/10./ Fabre A. Bidirectional current controlled PTAT current source, IEEE CASI 1994; 41: 922-925.


